Modern Control System Theory and Design

Min Huang, PhD

CheEng@TongjiU

Syllabus

- **Instructor: Huang, Min PhD**
- **Time and Place to meet**
- **Office Hours:**
- **Text Book and References**
  - **“Modern Control Engineering”, 5ed, (2010) [现代控制工程], Katsuhiko Ogata**
  - **Modern Control System Theory and Design, 2nd Ed., (1998) Stanley M. Shinners**
  - **Lecture Notes**

Syllabus

- **Assignments**
  - **Weekly assignments are to be given and are due at the following week regular lecture time**
  - **Late assignments will be accepted with 50% credit**
- **Examinations (Tentative Schedule)**
  - **Quiz, every time we meet**
  - **Midterm I,**

Syllabus

- Midterm II,
- Final,
- Term project

- **Policy**
  - Attendance +Quizzes 10%
  - Homework 15%, Midterm I/II 25%, Final 25%, Term project 25%.
  - Average exceeds
    - 90% A 80% B
    - 70% C 60% D

Syllabus

- **Tentative Schedule**
  - **General Concept of Control-System Design**
  - **Fourier and Laplace Transform**
  - **Transfer Function**
  - **Signal-Flow Graphs and Mason's Theorem**
  - **State-Variable**
  - **Matrix Form**
  - **Midterm I**

Syllabus

- Mathematical Modeling of Chemical Processes
- Transfer-Function Representation of Control-System Elements
- Time-Domain Response
- Development of Empirical Dynamic Models from Step Response Data
- Midterm II

Syllabus

- Performance Criteria
- Nyquist-Diagram
- Bode-Diagram
- Nichols Chart
- Root-Locus Method
- Linear Control-System Compensation and Design
- Final

General Concept of Control-System Design

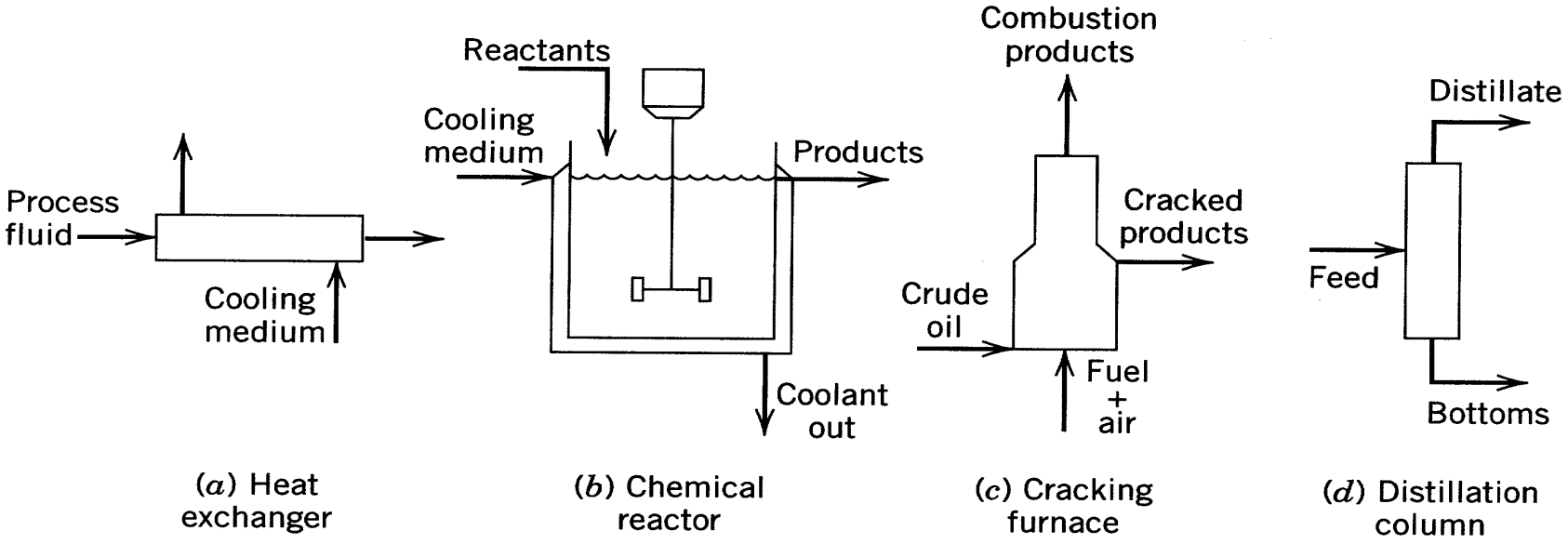
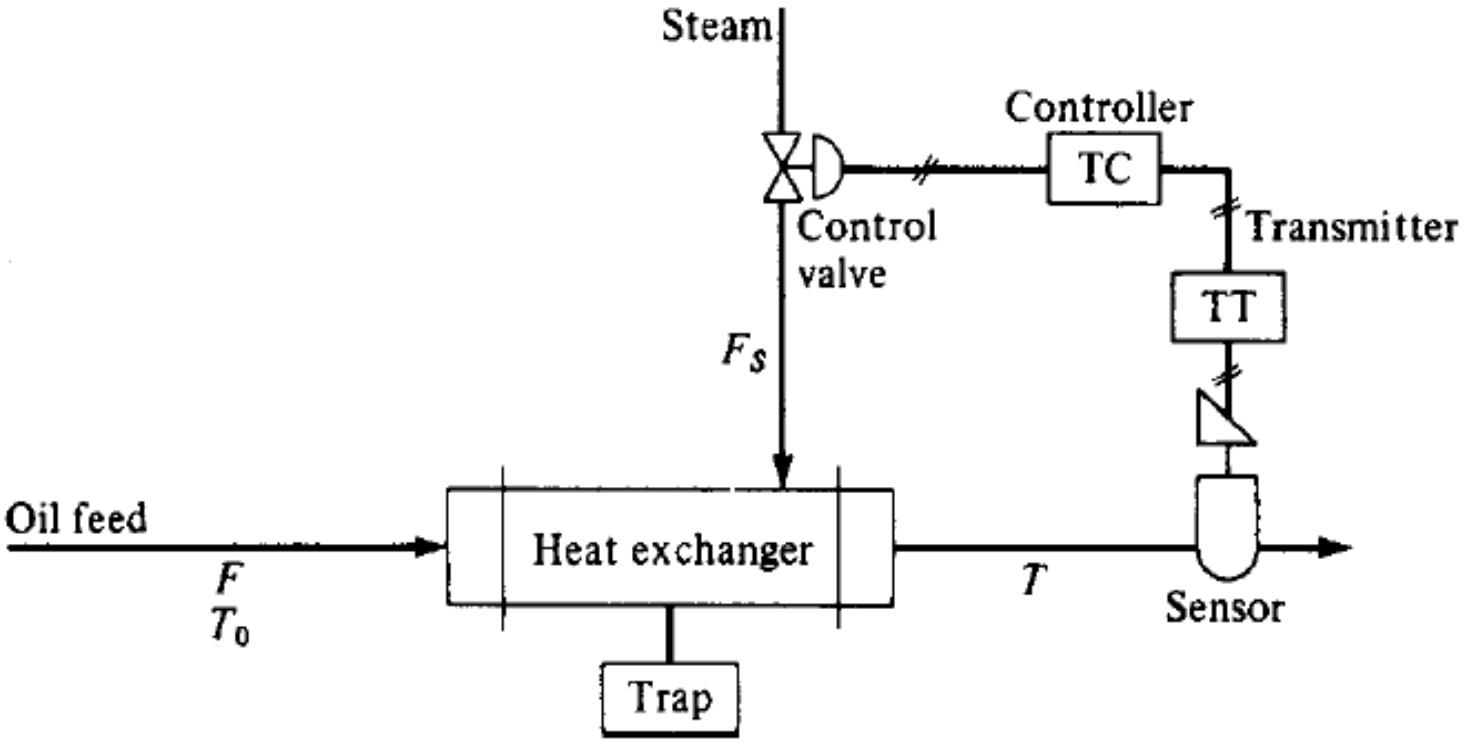
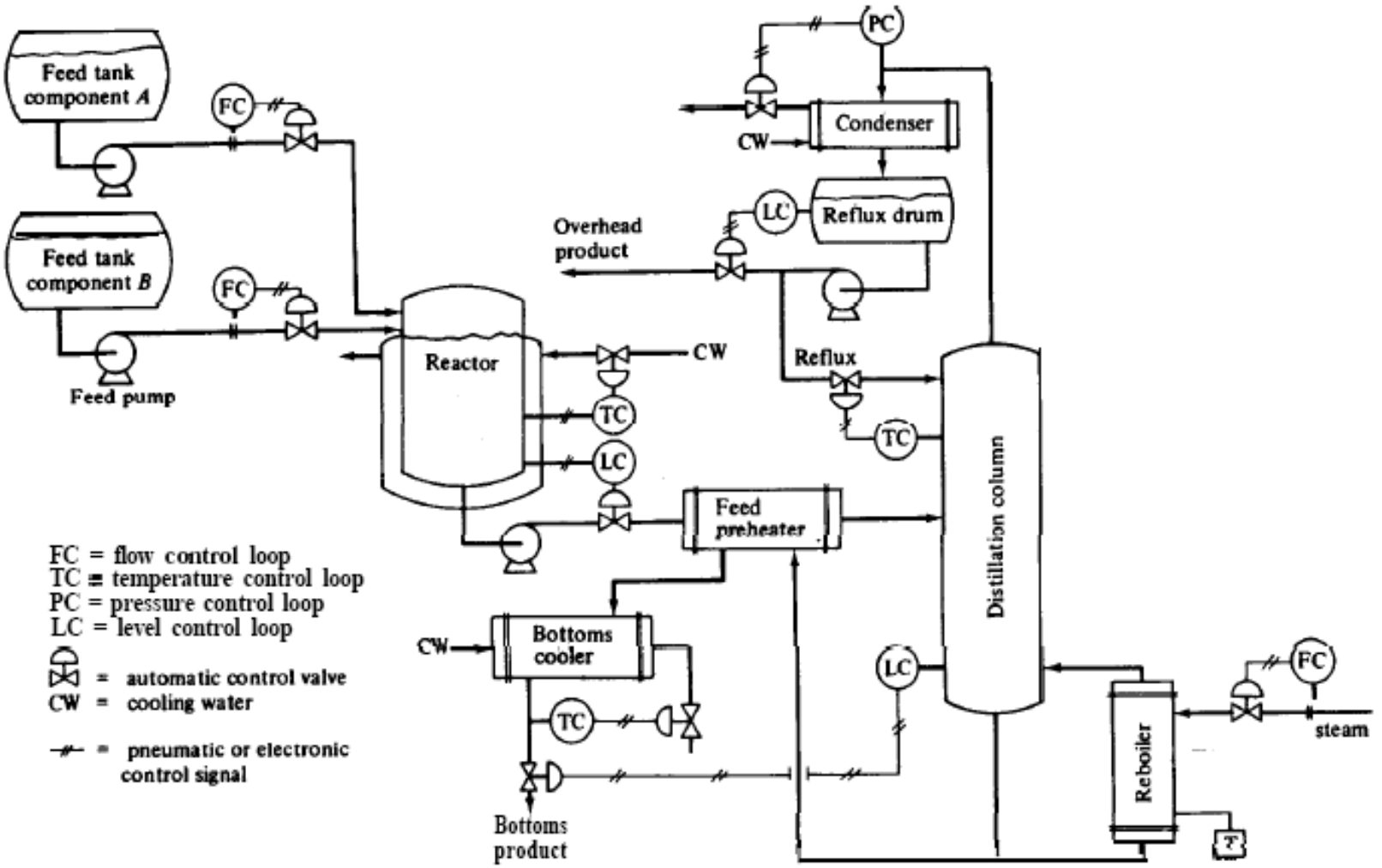


Figure 1.1 Some typical continuous processes.

Heat Exchanger



Typical Chemical Plant



Stirred-tank Blending System

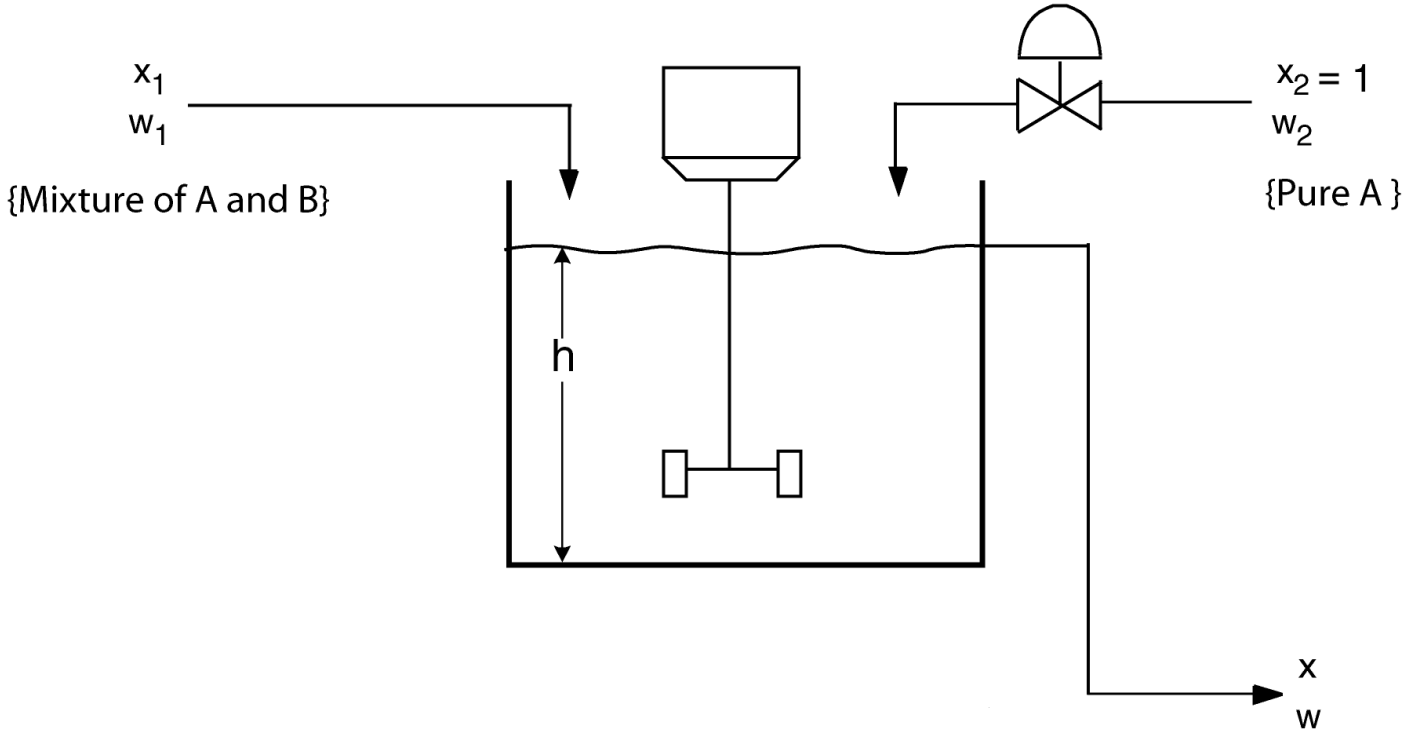


Figure 1.3. Stirred-tank blending system.

Stirred-tank Blending System

- **Notation:**
  - w_1, w_2 and w are mass flow rates
  - x_1, x_2 and x are mass fractions of component A
- **Control Objective:**
  - Keep x at a desired value (or "set point") x_{sp}, despite variations in $x_1(t)$. Flow rate w_2 can be adjusted for this purpose.

Stirred-tank Blending System

- **Terminology:**
  - **Controlled variable (or "output variable"):** x
  - **Manipulated variable (or "input variable"):** w_2
  - **Disturbance variable (or "load variable"):** x_1

Control Terminology

- **Controlled Variables - these are the variables which quantify the performance or quality of the final product, which are also called output variables.**
- **Manipulated Variables - these input variables are adjusted dynamically to keep the controlled variables at their set-points.**

Control Terminology

- **Disturbance Variables - these are also called "load" variables and represent input variables that can cause the controlled variables to deviate from their respective set points.**

Control Terminology

- **Set-point change - Implementing a change in the operating conditions. The set-point signal is changed and the manipulated variable is adjusted appropriately to achieve the new operating conditions. Also called servomechanism (or "servo") control.**

Control Terminology

- **Disturbance change - the process transient behavior when a disturbance enters, also called regulatory control or load change. A control system should be able to return each controlled variable back to its set-point.**

What value of w_2 is required to have $x = x_{sp}$

$$0 = \bar{w}_1 + \bar{w}_2 - \bar{w} \qquad (1\text{-}1)$$

$$\bar{w}_1\bar{x}_1 + \bar{w}_2\bar{x}_2 - \bar{w}\bar{x} = 0 \qquad (1\text{-}2)$$

$$\bar{w}_2 = \bar{w}_1 \frac{x_{SP} - \bar{x}_1}{1 - x_{SP}} \qquad (1\text{-}3)$$

Some Possible Control Strategies

- **Control Objective:**

  Keep *x* at a desired value (or "set point") x_{sp}, despite variations in $x_1(t)$.

  - **Method 1.** *Measure x and adjust w_2*
  - ***Method 2.*** *Measure x_1 and adjust w_2*
  - ***Method 3.*** *Measure x_1 and x, adjust w_2*

  This approach is a combination of Methods 1 and 2

Measure x and adjust w_2

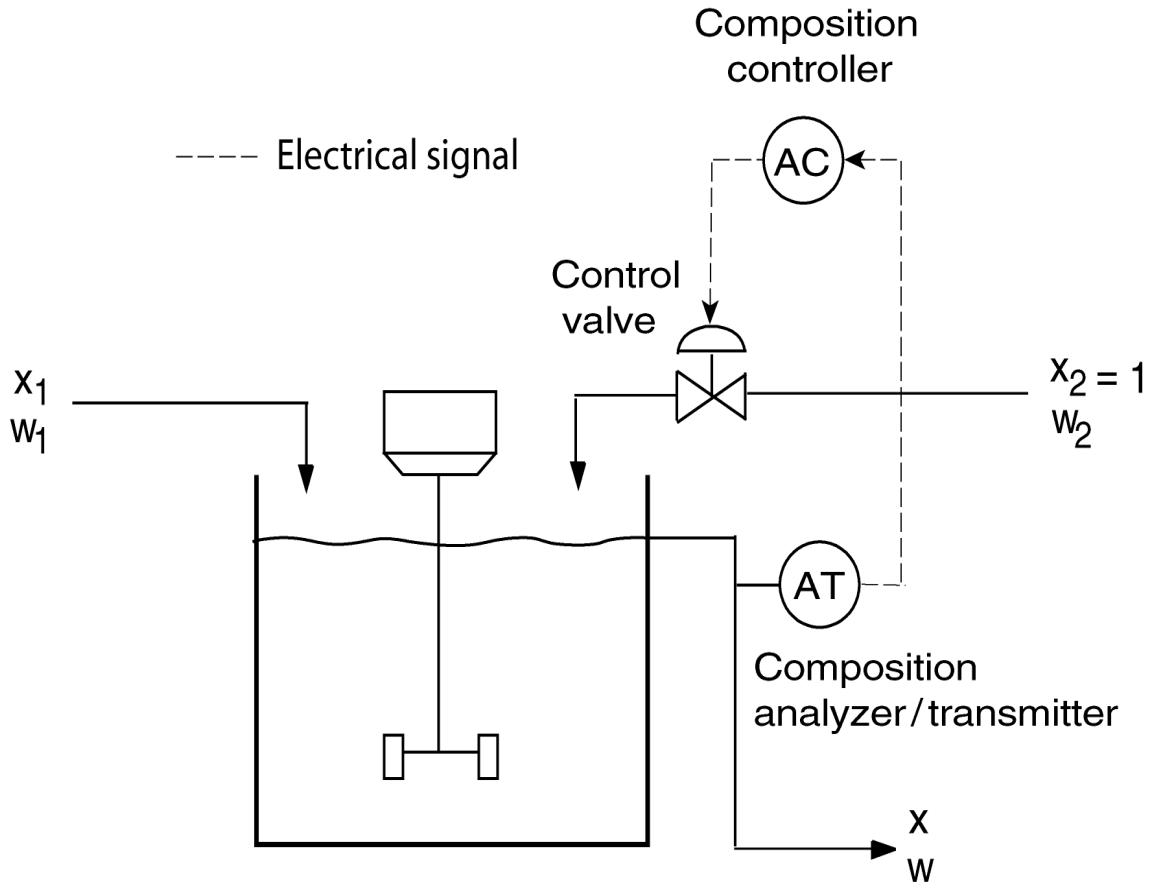
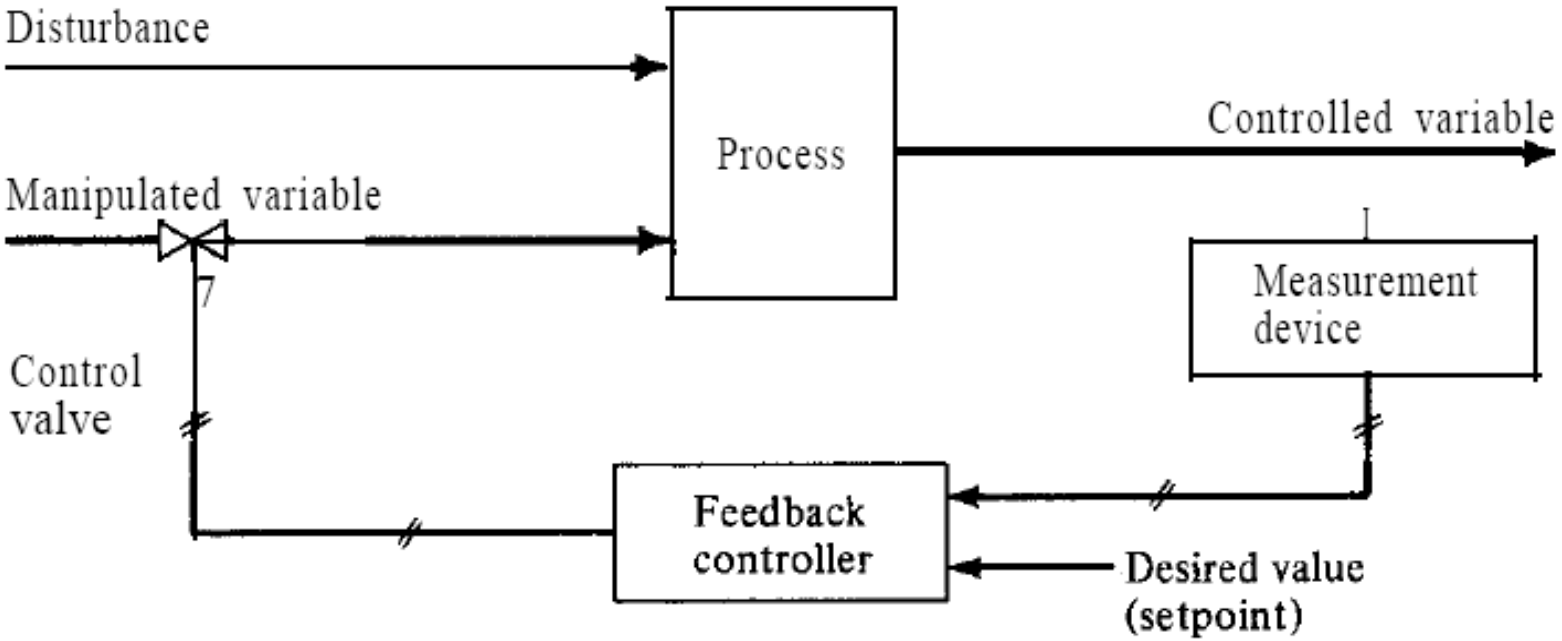


Figure 1.4. Blending system and Control Method 1.

Feed-back Control

Measure the controlled variable



Feed-back Control

- **Advantages**
  - **Corrective action is taken regardless of the source of the disturbance.**
  - **Reduces sensitivity of the controlled variable to disturbances and changes in the process (shown later)**

Feed-back Control

- **Disadvantages**
  - **No corrective action occurs until after the disturbance has upset the process, that is, until after *x* differs from x_{SP}.**
  - **Very oscillatory responses (close-loop system + time delay), or even unstable**

Measure x_1 and adjust w_2

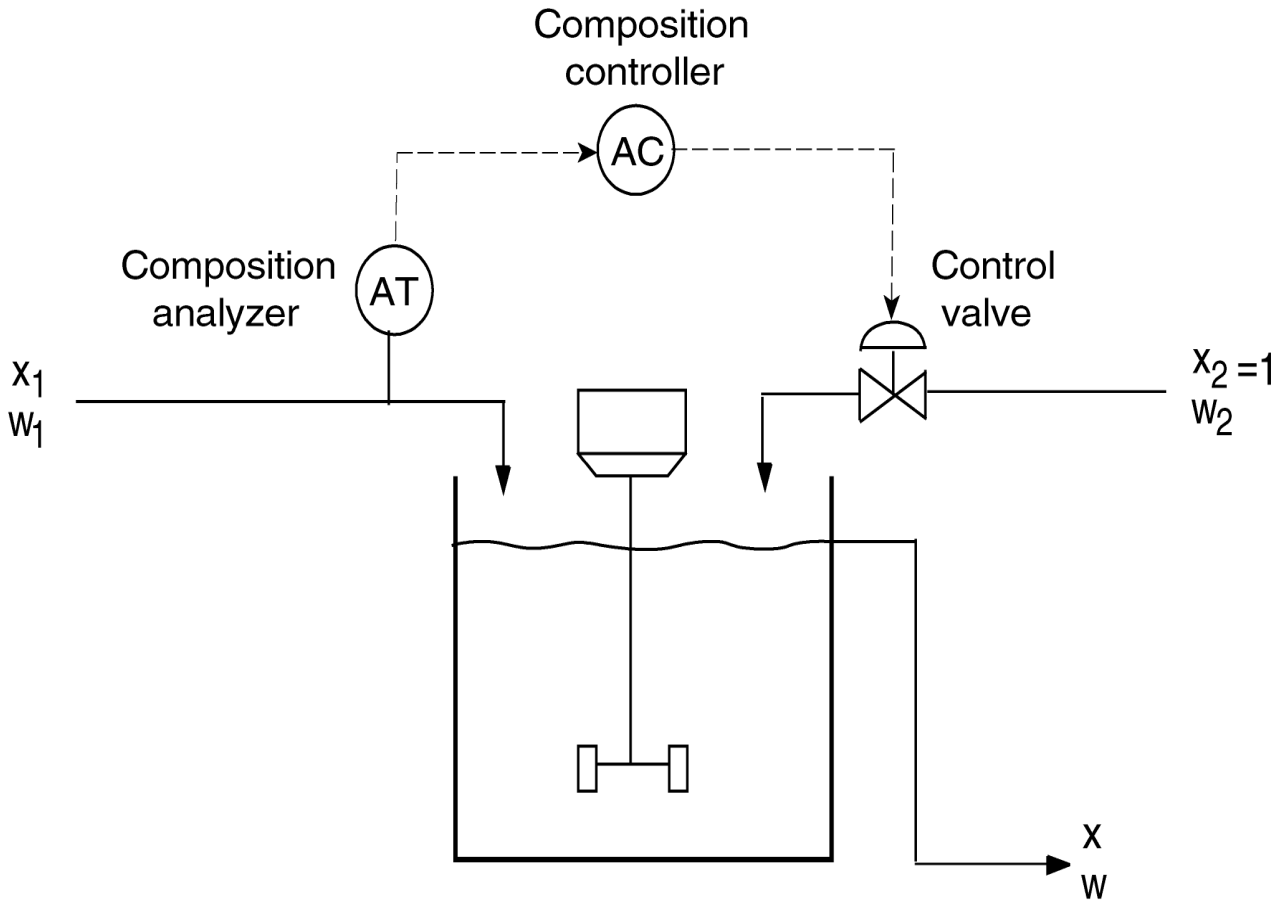


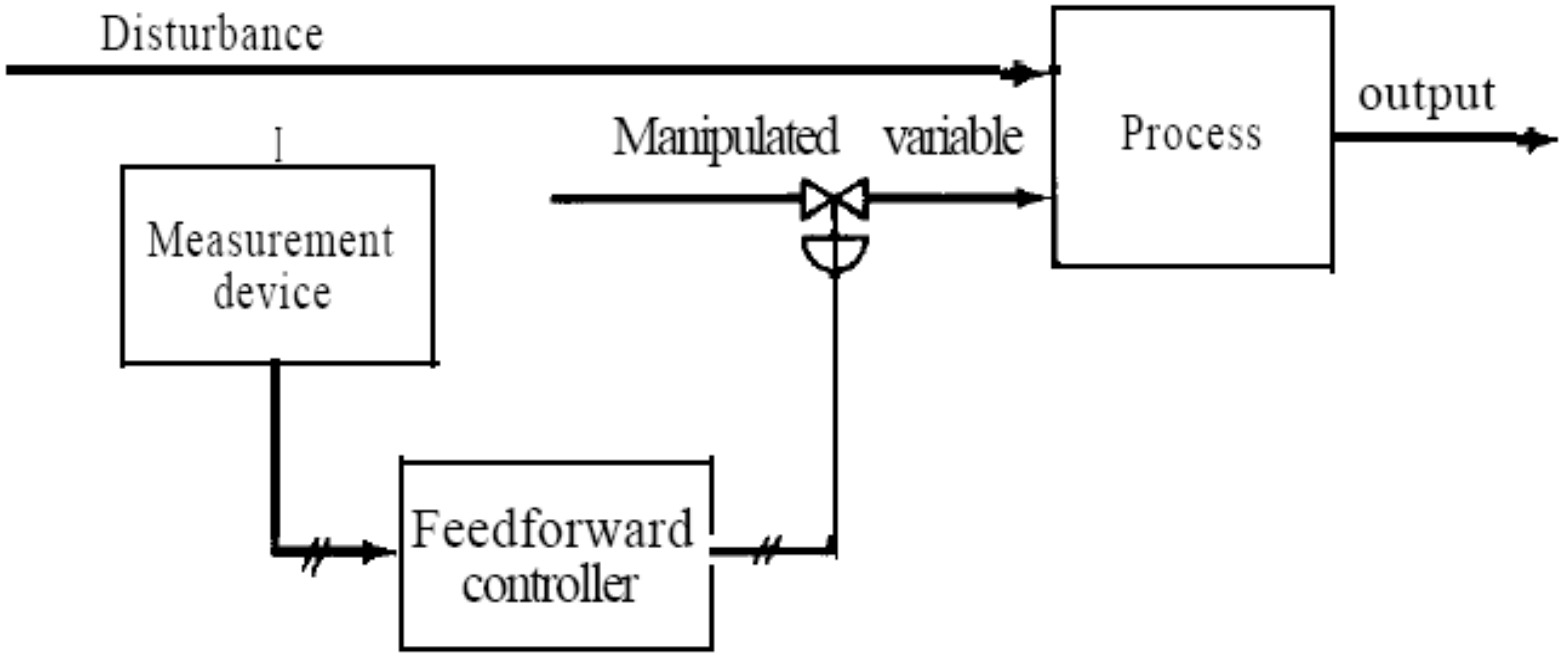
Figure 1.5. Blending system and Control Method 2.

Feed-forward Control

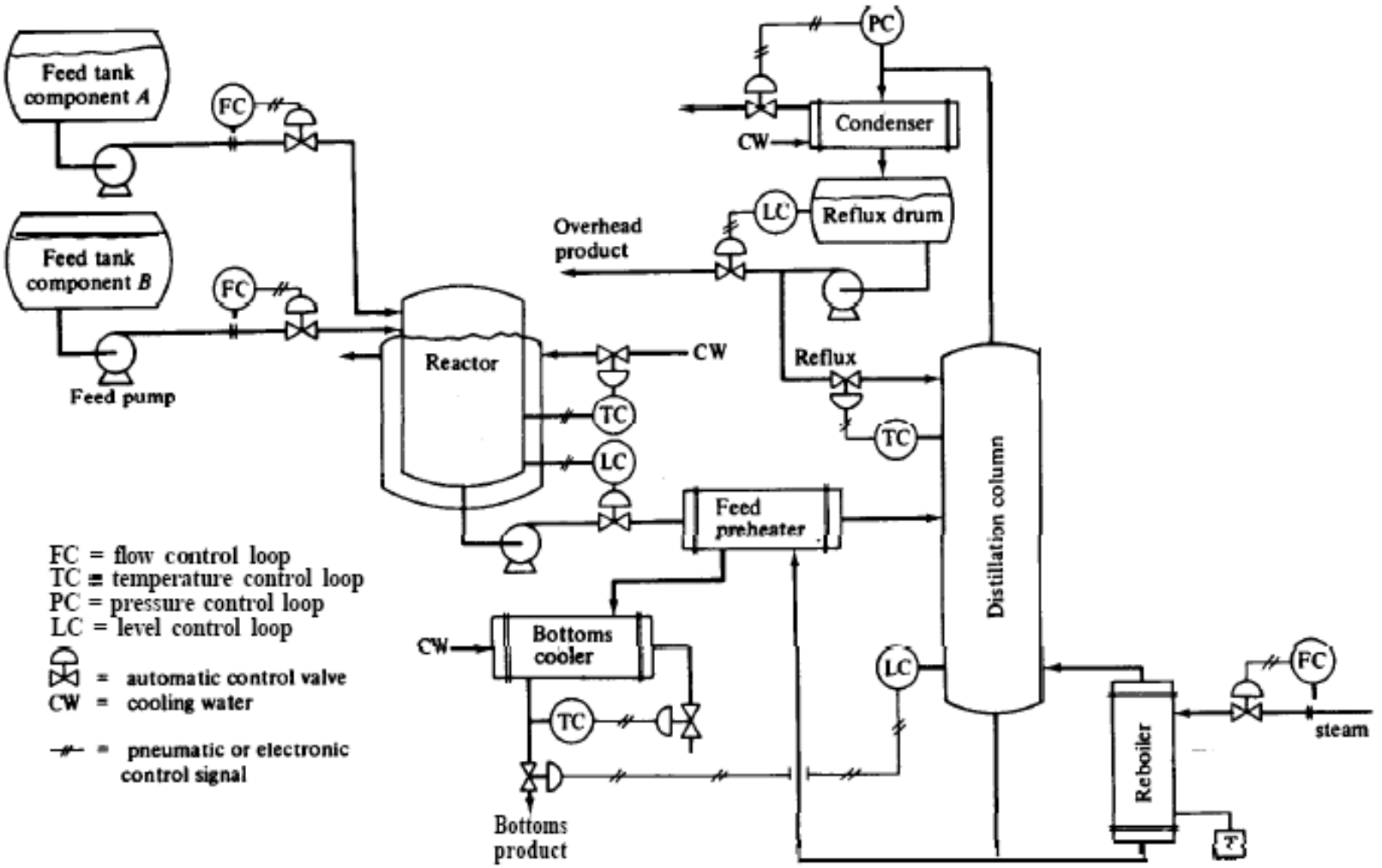
- **Advantage**
  - **Correct for disturbance before it upsets the process**
- **Disadvantage**
  - **Must be able to measure the disturbance**
  - **No corrective action for unmeasured disturbances**

Feed-forward Control

- **Measure a disturbance variable**

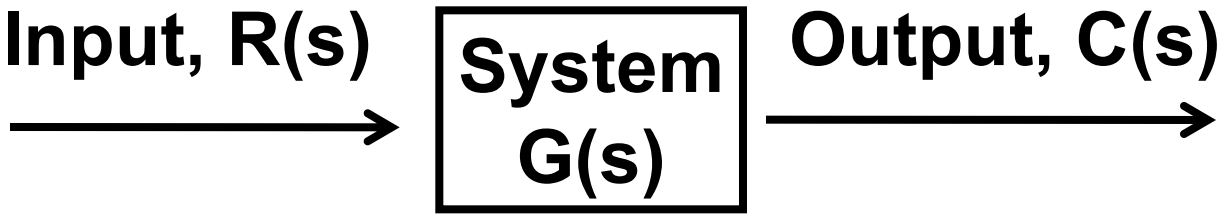


Typical Chemical Plant



Block Diagram

- **Signal-flow representation of a physical system**



Steering of an Automobile

- Pre adjustment of the steering wheel when the alignment is poor
- Stop the automobile in front of the stop sign or traffic light
- Negotiate a turn at the cross-section
- Adjust the steering wheel to negotiate the curvatures of the road

Steering of an Automobile